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# Growth curves and productivity of Holstein-Friesian cows bred for heavy or light mature live weight

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## ABSTRACT

This paper presents data for live weights (LW) from birth to maturity, and for yields of milk and milksolids (MSY) per lactation, from two lines of Holstein-Friesian cows bred for heavy (H) or light (L) mature LW. Compared with the Brody, Gompertz and Logistic functions, the Von Bertalanffy function provided the best fit to the LW data, and prediction from this function has been used in the following analyses. The breeding values (BV) for LW of the sires (H: 86.3 kg; L: 31.0 kg) and maternal grandsires (MGS) (H: 55 kg; L: 38 kg) used to develop the H and L LW lines were higher ($P < 0.001$) for the H line than for the L line, and they were significantly associated with the actual birth weight (H: 41 kg; L: 35 kg) and mature live weight (H: 520 kg; L: 467 kg) of the cows. The heavy sires also had significantly higher BV for yield of milk (H: 1037 l; L: 737 l), milkfat (H: 33.0 kg; L: 27.5 kg), and milk protein (H: 31 kg; L: 22 kg), and the H cows produced more milk (H: 4708 l; L: 4323 l), and MSY (H: 364 kg; L: 348 kg) than the L cows. However, L sires had slightly higher ($P = 0.07$) value for Breeding Worth than the H sires (H:37; L:46), and there were only small differences in yields of milk or MSY between the two lines when these were expressed per kg of LW, per kg of $LW^{0.75}$ or per tonne of dry matter required (H: 84 kg MSY/tonne DM; L: 87 kg MSY/tonne DM). The results indicate that the extra MSY by the H cows (+ 16 kg) almost compensated for the effect of their extra LW (+ 46 kg), so that the H cows were only slightly less efficient than the L cows, as predicted by their respective sire's Breeding Worth.

**Keywords:** Mature live weight; growth curves; milksolids yield; dairy cows.

## INTRODUCTION

Relative to average live weight (LW) animals, heavier LW cows typically produce more milk (Ahlborn and Dempfle, 1992). However, cow LW also affects dairy farm profitability in the New Zealand pasture-based dairying system through maintenance requirements and marginal returns from beef from culled cows and calves sold for slaughter (Spelman and Garrick, 1997). The genetic evaluation system of cows and bulls in New Zealand includes LW of the lactating cow in the breeding objective and places a negative relative economic value on this component. This is done because the cost of the higher maintenance requirements is relatively larger than the benefit of the higher return from beef (Livestock Improvement Corporation, 1994).

Since 1989 two genetic lines of Holstein-Friesian cows, selected for heavy (H) or light (L) mature LW, have been developed at the Dairy Cattle Research Unit, Massey University. The overall aims of the project are to investigate the effects of genetic differences in cow LW on i) the pattern of growth from birth to maturity, ii) onset of puberty of the replacement heifer, iii) the feed conversion efficiency of lactating cows and growing heifers, iv) incidence of calving difficulty, and v) reproductive performance.

The pattern of growth of individual cows contained in a sequence of live weight-age data points can best be summarised in a few biologically interpretable parameters by means of growth curve analyses (Fitzhugh, 1976). This paper presents the results from the analysis of growth curves of individual cows, the yield of milksolids and estimated feed conversion efficiency of cows from the H and L lines born between 1990 and 1995.

## MATERIALS AND METHODS

### Experimental design

High genetic merit Holstein-Friesian cows from the base (B) herd at the Dairy Cattle Research Unit, Massey University, New Zealand, were stratified by LW within parities, heavier cows were mated to bulls with high BV for LW and lighter cows were mated to bulls with low BV for LW. In the subsequent years, H-sired and L-sired cows were mated back to H or L bulls, respectively (Figure 1). More details of the mating strategy followed to develop the H and L lines are given by Garcia-Muñiz *et al.*, (1998). Breeding values of sires for yields of milk (*l*), milkfat (kg), milk protein (kg), live weight (kg) and survival (%), weighted by their respective relative economic values ($), are combined into an index of farm profitability termed 'Breeding Worth' (BW). BW represents the expected ability of an animal to breed replacements, which are efficient converters of feed into profit (Livestock Improvement Corporation, 1997).

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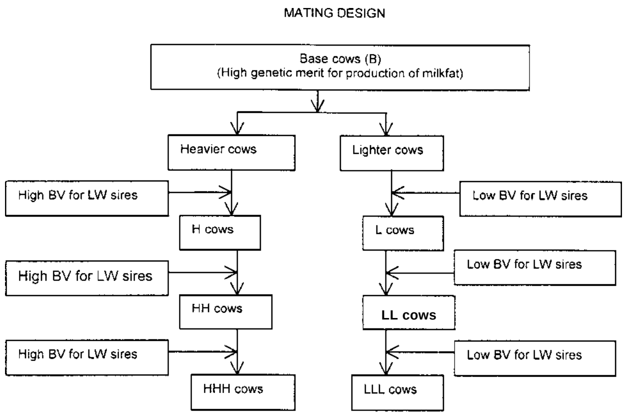
**FIGURE 1:** Mating design to develop the heavy and light live weight selection lines of Holstein-Friesian cows.




## Management of animals and information recorded

Every year, all heifer calves sired by H or L bulls were kept as replacements and reared on the home-farm until weaning at about 12 weeks of age. After weaning, calves were managed as a single group and grazed off the home-farm until two months before first calving, then returned back to the home-farm and grazed together with the adult herd on pastures of rye-grass white clover all year round. LW was recorded at birth (except for the 1993 born calves) and at weaning. After weaning, LW was recorded monthly up to three months before first calving, and at calving. After calving LW was recorded monthly until three months before the following calving.

Individual cow milk yield (a.m. and p.m.) was recorded daily using an automatic milk recording system (Westfalia Separator). Milk composition (fat % and protein %) and milk volume were measured for individual cows on 6 to 8 occasions during each lactation by routine herd testing carried out by Livestock Improvement Corporation personnel. Dry matter intake per cow per lactation was calculated from the average LW during lactation (predicted from the growth curve), and the yields of milk, fat and protein, as described by Van der Waiij *et al.*, (1997). In total there were 97 cows from parity 2 to 5 (50 H and 47 L) with LW-age records to fit individual growth curves. These cows, which were the offspring of 12 H and 12 L bulls, provided for analysis 232 lactations (119 from H and 113 from L-cows) with yields of milk and its components.

## Mathematical and statistical methods

Nonlinear regression [PROC NLIN, SAS, (1995)] was used to fit to the lifetime live weight-age records of individual cows the following four non-linear equations (Fitzhugh, 1976):

$W_t = A(1\text{-}be^{-kt})$ ...................... Brody [1]

$W_t = A(1\text{-}be^{-kt})$ ...................... Von Bertalanffy [2]

$W_t = A(1\text{-}be^{-kt})$ ...................... Logistic [3]

$W_t = Ae^{-be^{-kt}})$ ...................... Gompertz [4]

For each equation, $\boldsymbol{W_t}$ is live weight (kg) at age $\boldsymbol{t}$ (months), $\boldsymbol{e}$ is the base of the natural logarithms, and $\boldsymbol{A}$, $\boldsymbol{b}$ and $\boldsymbol{k}$ are parameters to be estimated. $\boldsymbol{A}$ is asymptotic value for LW as $\boldsymbol{t}\varnothing$ , generally interpreted as average mature weight; $\boldsymbol{b}$ is constant of integration or the time scale parameter that adjusts for situations in which $\boldsymbol{W_0}$ (initial weight) and/or $\boldsymbol{t_0}$ (time of origin) do not equal zero, and $\boldsymbol{k}$ is the rate at which a logarithmic function of live weight changes linearly per unit of time, and is generally interpreted as a maturation index (Fitzhugh, 1976). Large $k$ values indicate early maturing animals, and vice versa (López de Torre *et al.*, 1992).

Criteria to assess model goodness of fit were i) the relative size of the mean square of the residuals after the iterative procedure converged (Papajsick and Bodero, 1988; Sherchand, *et al.*, 1995; Ramirez *et al.*, 1994); ii) difficulty of fitting, as assessed by the number of cows failing to converge within the specified restrictions for parameter estimates, and iii) bias of the observed weights at birth and at maturity from those predicted by the growth equation (López de Torre *et al.*, 1992; Mezzadra and Miquel, 1994). Observed mature weight was the average LW recorded during the last lactation.

Differences between genetic lines for the parameters of the growth curve giving the best fit, and for yield variables, were tested by least squares analysis of variance using PROC GLM (SAS, 1995). Differences between the H and L lines for yield of milk or milksolids and yield per kg of $LW^{0.75}$/per lactation were tested by fitting a linear model containing the fixed effects of year of calving, lactation number, genetic line, linear and quadratic effects of lactation length, and the random effects of sire nested within genetic line, and cow nested within sire and genetic line. The mean square (MS) of sire nested within genetic line was used to test differences between genetic lines. The corresponding test for sires used the MS of cow nested within sire and genetic line. All other tests of significance used the residual MS.

Differences for birth weight of the cow and the parameters $\boldsymbol{A}$, $\boldsymbol{b}$, and $\boldsymbol{k}$ of the growth curve were tested by fitting a linear model that included the fixed effects of dam parity, genetic line, the linear regression of cow date of birth, and the random effect of sire nested within genetic line. The MS of genetic line was tested against the MS of sire nested within genetic line. All other tests of significance used the residual MS. The relationship between the sire of cow BV for LW and the cow's weight at birth and at maturity was determined using linear regression analysis.

## RESULTS

As planned, sires contributing to the development of the H line had significantly higher ($P < 0.0001$) breeding values for live weight than L-sires. Sires of the H line cows also had significantly higher ($P < 0.0001$) breeding values for yield of protein, fat and milk, while the L-line sires had a slightly higher ($P = 0.07$) average for Breeding Worth(Table 1).

The Brody and the Von Bertalanffy equations predicted more accurately immature live weights than the Logistic or the Gompertz functions, as evidenced by the

**TABLE 1:** Least squares means of Breeding Worth and Breeding Values for production traits of the sires used to develop the heavy and light live weight selection lines of Holstein-Friesian cows[1]

| Item | Units | Genetic line: Heavy | Genetic line: Light | SE of the difference | P |
|---|---|---|---|---|---|
| Breeding worth BW | $ | 37.3 | 45.9 | 4.1 | 0.068 |
| Milk volume BV | *l* | 1037.0 | 737.0 | 63.9 | 0.0001 |
| Milkfat yield BV | kg | 33. | 27. | 1.0 | 0.0001 |
| Milk protein yield BV | kg | 31.0 | 22.0 | 1.6 | 0.0001 |
| Live weight BV | kg | 86.0 | 31.0 | 3.6 | 0.0001 |
| Survival BV | % | 0.29 | 0.33 | 0.28 | 0.41 |

[1] 50 Heavy cows sired by 12 H bulls, and 47 Light cows sired by 12 L bulls.

smaller differences between the observed and the predicted birth weights. The Brody function, however, did not reach convergence for 10 H and 9 L cows. Regarding mature weight, the Logistic function showed the highest agreement between observed and predicted weights, with the other three functions slightly overestimating this parameter. Overall, however, the Von Bertalanffy function provided the best fit as it had the lowest residual mean square when fitted to the data of L cows, and ranked similar to the Brody and Gompertz when fitted to the data of H cows (Table 2). Thus, the Von Bertalanffy function was used for the rest of the calculations in this paper. Figure 2 shows the fit of this function to the live weight-age data of H and L cows.

On average H cows were 6.0 kg or 17% heavier ($P < 0.001$) at birth and 46 kg or 10% heavier ($P < 0.0001$) at maturity than L cows (Table 3). The breeding values for LW of sires and MGS of the cow were significantly related to the cow's birth weight and her mature weight. The respective regression coefficients predicted an average difference of 10 kg at birth and 76 kg at maturity for cows sired by bulls that differed by 100 kg in BV for LW.

Least squares means for yield per lactation, expressed per cow and per kg of metabolic weight, of milk, and milksolids are presented in Table 3 and Figure 3. Live weight during lactation was calculated from the growth curve as the mean of LW predicted at calving, mid lactation and at drying off. Heavy cows had higher calculated feed requirements and they produced more milk, milkfat, milk protein and milksolids per lactation than L-cows. However, when yields per lactation were scaled by $LW^{0.75}$ or per calculated tonne of dry matter required, the differences between the H and L cows disappeared.

**TABLE 2:** Average residual mean squares (MS) and their ranks, and agreement between weights at birth and at maturity with those predicted from the Brody, Gompertz, Logistic or Von Bertalanffy growth equation for heavy or light Holstein-Friesian cows

| Genetic line | Equation | Residual MS | Rank MS[1] | Cow birth weight (kg): Observed | Predicted | Difference[2] | Cow mature weight (kg): Observed | Predicted | Difference[2] |
|---|---|---|---|---|---|---|---|---|---|
| Heavy | Brody | 843 | 3[a] | 41 | 32 | -9 | 492 | 556 | 64 |
| | Gompertz | 791 | 1[a] | 41 | 161 | 120 | 484 | 522 | 38 |
| | Logistic | 913 | 4[b] | 41 | 73 | 32 | 484 | 482 | -2 |
| | Von Bertalanffy | 820 | 2[a] | 41 | 49 | 8 | 485 | 522 | 37 |
| Light | Brody | 763 | 2[b] | 35 | 28 | -7 | 433 | 497 | 64 |
| | Gompertz | 780 | 3[b] | 35 | 137 | 102 | 430 | 510 | 80 |
| | Logistic | 729 | 4[b] | 35 | 63 | 28 | 428 | 427 | -1 |
| | Von Bertalanffy | 700 | 1[a] | 35 | 44 | 9 | 430 | 470 | 40 |

[1] Residual MS were ranked from smallest to largest.

[a,b] Within column and genetic line, ranks with different superscript are different ($P < 0.05$).

[2] Difference = Predicted – Observed.

**FIGURE 2:** Data for age and live-weight of genetically heavy (– •) or light (--- o) Holstein-Friesian cows fitted by a Von Bertalanffy function.

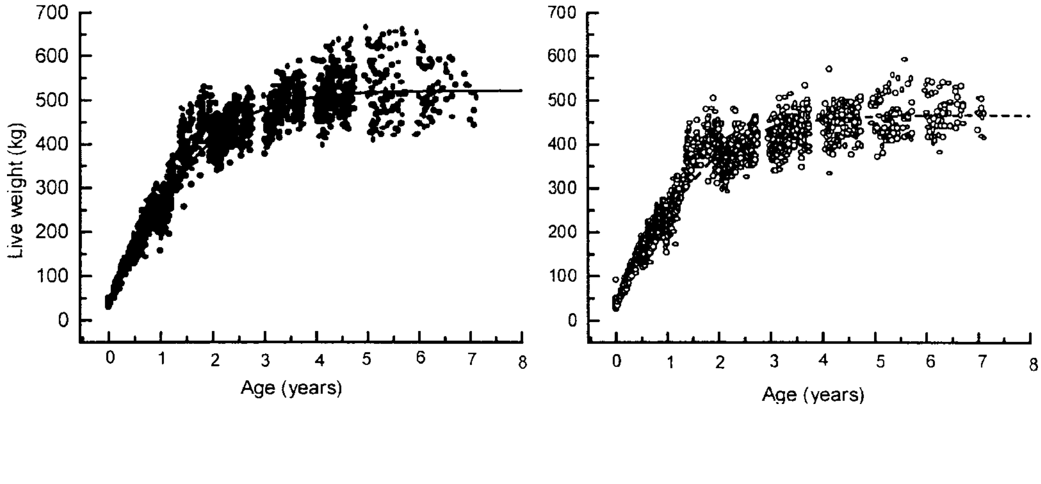


**TABLE 3:** Growth and lactation variables in the heavy and light live weight selection lines

| | Genetic line | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Heavy | | | Light | | | Difference[1] | P |
| | Growth variables[2] | | | | | | | |
| Cow birth weight (kg)[3] | 40.7 | ± | 0.64 | 34.7 | ± | 0.81 | 6.0 | 0.001 |
| Parameters of the growth curve[4] | | | | | | | | |
| ***A*** (kg) | 516 | ± | 7.5 | 470 | ± | 7.3 | 46.0 | 0.001 |
| ***b*** | 0.54 | ± | 5.1 x $10^{-3}$ | 0.55 | ± | 5.0 x 10-3 | -0.01 | n.s |
| ***k*** (%/month) | 8.8 | ± | 0.2 | 8.9 | ± | 0.2 | -0.16 | n.s |
| | Lactation and feed conversion variables[5] | | | | | | | |
| Milk | | | | | | | | |
| *l*/cow/lactation | 4708 | ± | 132 | 4323 | ± | 129 | 385.0 | 0.0001 |
| *l*/cow/kg $LW^{0.75}$ | 44.3 | ± | 1.4 | 43.9 | ± | 1.3 | 0.4 | 0.177 |
| Milksolids | | | | | | | | |
| kg/cow/lactation | 364 | ± | 12 | 348 | ± | 12 | 16.0 | 0.021 |
| kg/cow/kg $LW^{0.75}$ | 3.38 | ± | 0.13 | 3.42 | ± | 0.12 | -0.04 | 0.612 |
| Calculated dry matter required (kg/cow/lactation)[6] | 4349 | ± | 81 | 4022 | ± | 80 | 327.0 | 0.0001 |
| Calculated feed conversion (kg of MSY/tonne DM) | 84 | ± | 1.8 | 87 | ± | 1.7 | 3.0 | 0.299 |

[1] (Heavy – Light).

[2] Model $\hat{y}$ = $\mu$ = + dam parity + genetic line + sire(genetic line) + b(cow date of birth) + error.

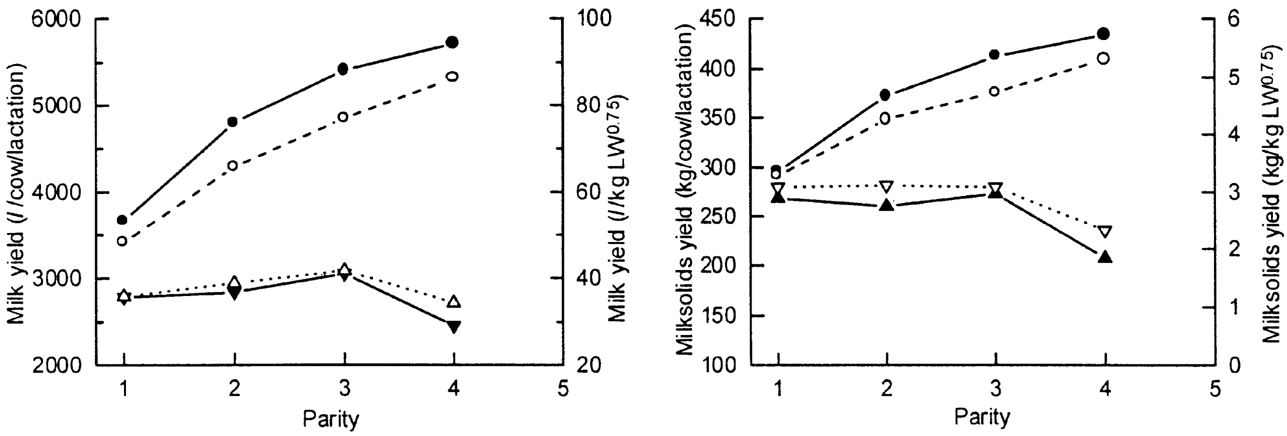
[3] Birth weight records: 47 H, 36 L.

[4] $W_t = A(1 - be^{-kt})^3$, where $W_t$ = LW at time t (months); ***A*** = asymptotic (mature) weight; ***b*** = constant of integration; ***k*** = growth rate parameter. Number of records 50 H, 47 L.

[5] Model $\hat{y}$ = $\mu$ + year of calving + parity + genetic line + sire(genetic line) + $b_1$ (days in milk) + $b_2$(days in milk)$^2$ + error.

[6] Calculated as: Dry matter intake (kg/cow) = [1.83* Milk yield (*l*) + 56.10*Fat yield (kg) + 31.77*Protein yield (kg) + 231.26* $LW^{0.75}$ ]/10.8.

**FIGURE 3:** Yield per lactation (heavy, —●, light, ---○) and per kg of $LW^{0.75}$ (heavy, —▲ , light,▽) of milk, and milksolids by heavy or light Holstein-Friesian cows




## DISCUSSION

Results for the comparison of growth equations are similar to those reported in the literature for dairy and beef cattle. In a study comparing the growth curves of Dutch Friesian, British Friesian, and Holstein-Friesian cows, a reparameterized form of the Von Bertalanffy function also provided the best fit to the data when compared to the Gompertz, Brody and Logistic functions (Bakker and Koops, 1977). López de Torre *et al.*, (1992) found similar results when the Gompertz, Richards and Von Bertalanffy functions were fitted to the live weight-age data of Retinta breed cows. Mezzadra and Miquel (1994) also obtained lower residual sums of squares with the Von Bertalanffy function, when they fitted LW-age data of Angus, Criollo and reciprocal crossbred cows to the Brody, Gompertz, Logistic, Richards and Von Bertalanffy functions. Jolicoeur (1985) argues that the poor fitting of the Gompertz and the Logistic functions to post-natal growth is due to the fact that these two functions are exclusively sigmoid in shape and have both a lower as well as an upper asymptote. For the present data set, increases in LW after birth with advanced age did not show a sigmoid pattern of growth (Figure 2). Thus, growth functions like the Brody or Von Bertalanffy that pass through the origin or near to it and have an upper asymptote are more appropriate to describe this type of data (Jolicoeur, 1985).

The estimated regression coefficient of mature LW on sire of cow BV for LW of 76 kg was not significantly different from the expected value of 50 kg. The observed difference between estimated and expected may be due to the fact that the Von Bertalanffy equation slightly overestimated the cow's mature weight.

The differences in LW and MSY in favour of the H cows were expected, since they were the offspring of sires with significantly higher BV for LW, milk volume, fat and protein yield. However, the H cows were heavier throughout their life, and when yields per lactation were scaled by $LW^{0.75}$ the differences in yield between the lines disappeared. Despite their heavier mature weights and higher MSY, cows from the H line were expected to be as efficient as cows from the L line since their sires had similar genetic merit for farm profitability (i.e. similar breeding worth). This was indeed the case. When feed requirements were calculated for both lines from the actual LW and milksolids yield, the resultant values for feed conversion efficiency (kg of MSY/tonne of DM required) were similar for both lines. This conclusion agrees with direct measurement of feed intake and milk production by some of these cows in another experiment (Laborde *et al.*, 1998 in press, this volume).

The results from this study suggest that the published values for Breeding Values of sires are reliable predictions of their daughters' actual performance, and that the overall estimate of Breeding Worth is closely related to the cows' feed conversion efficiency.

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